

Modeling Terrestrial Ecosystem Dynamics and Carbon Biogeochemistry

Workshop on ***Remote Sensing in the NACP***
August 20-21, 2004

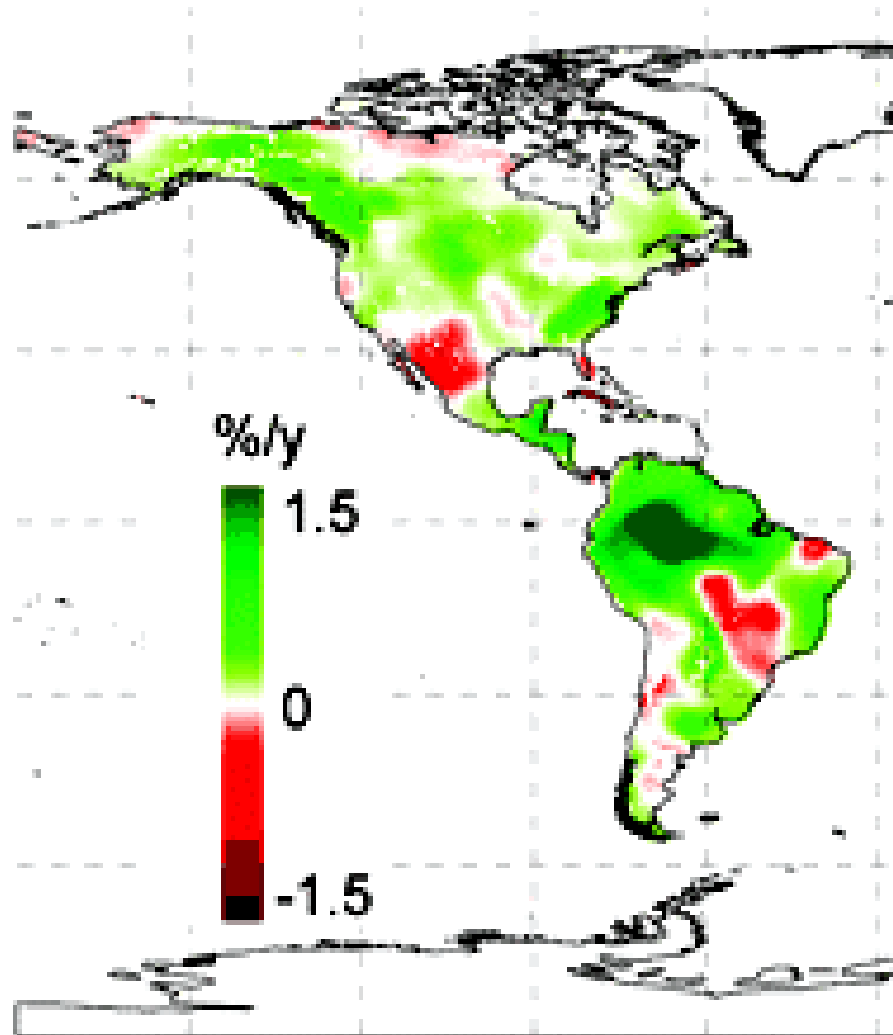
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From the NACP Science Implementation Strategy (SIS)

“Models will have a new emphasis on managed ecosystems (agriculture, forest management, urban/suburban landscapes)...resolution must be improved to hourly at < 10km” (SIS, p. 31).

“The size of soil C and N pools and forest stem C in many cases will determine whether the (ecosystem) flux is a source or a sink (SIS, p. 34).

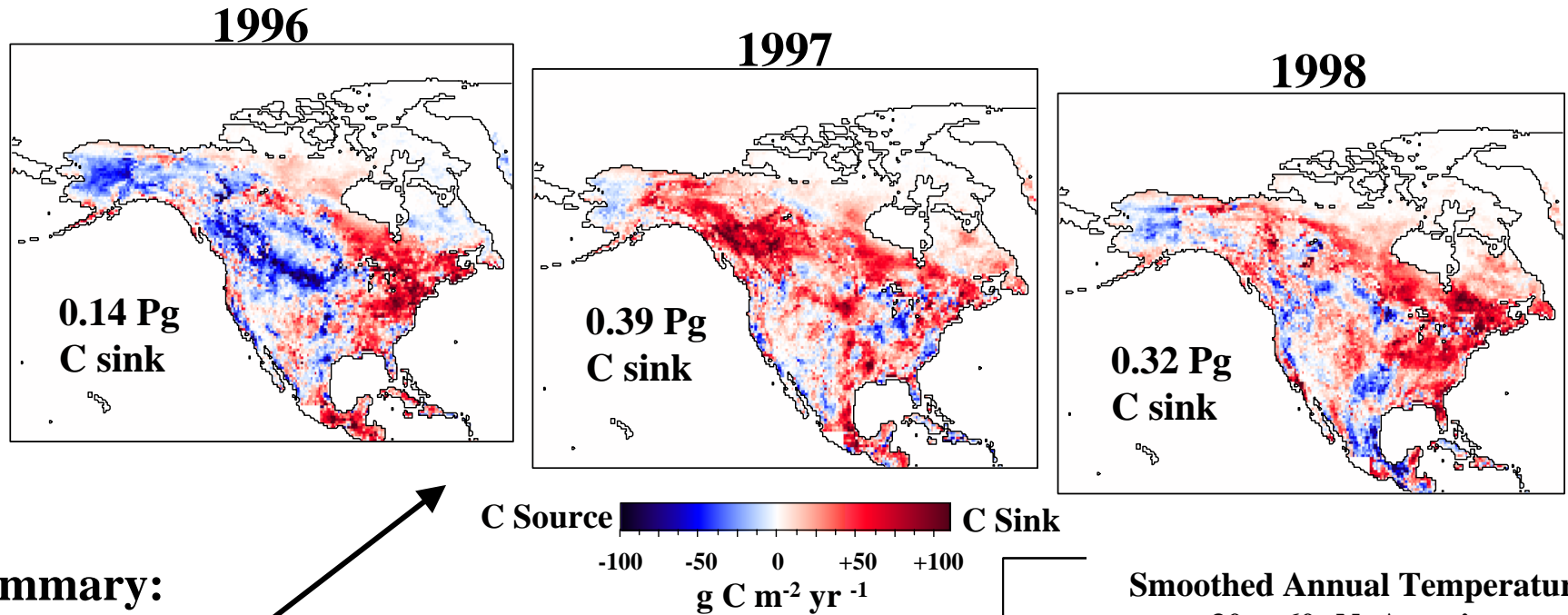
Spatial distribution of linear trends in estimated NPP from 1982 to 1999
(Source: Nemani et al., 2003, *Science*)



NPP calculated with mean FPAR and LAI derived from AVHRR GIMMS and PAL data sets.

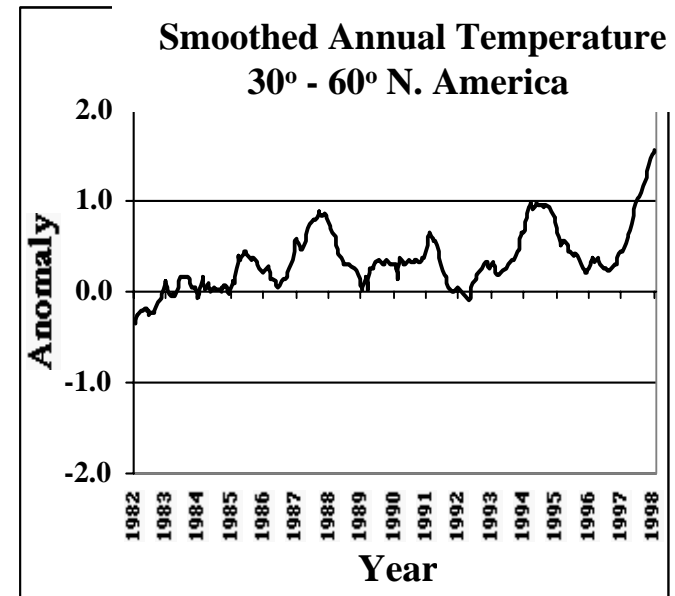
Prediction of the North American Carbon Sink

Fall AGU '01 B52B-03 "The North America Carbon Sink from 1982-1998
Estimated using MODIS Algorithm Products"



Summary:

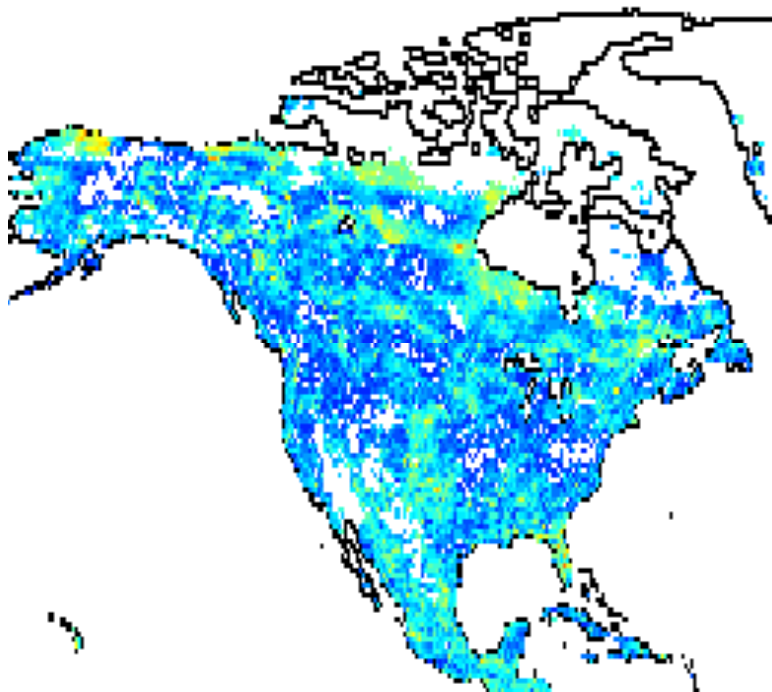
- (a) Since 1982, the terrestrial ecosystem sink for atmospheric CO_2 in North America has been fairly consistent (at ca. $0.3 \text{ Pg C per year}$), except during relatively cool periods (Potter et al., 2003, *Global & Planetary Change*).
- (b) Regional warming has had the greatest impact on high latitude (boreal) forest sinks for atmospheric CO_2 in North America.



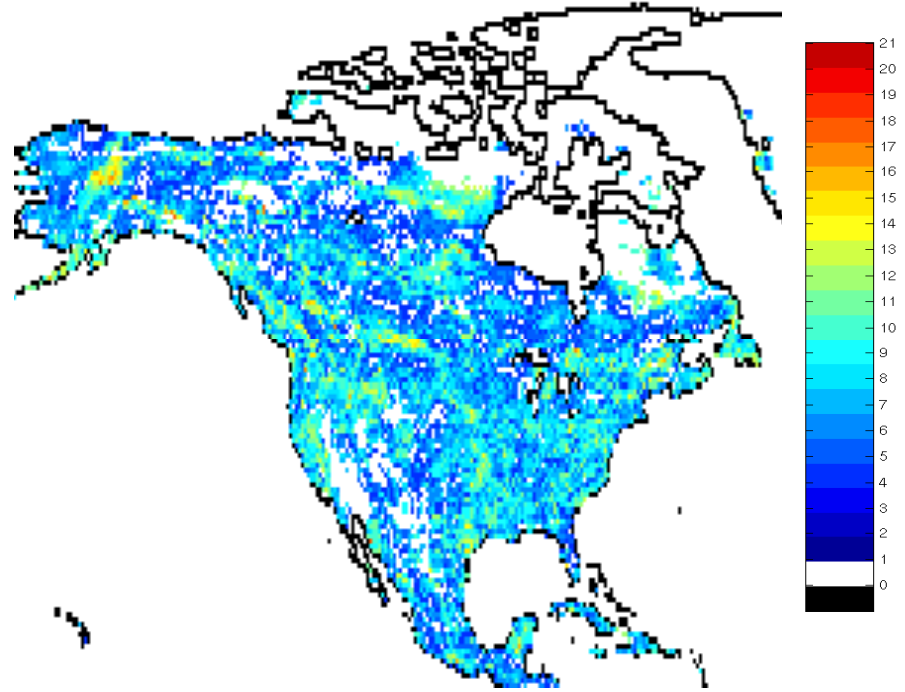
Location of NEP Monthly Anomalies

NASA-CASA 17-yr time series (1982-1998)

(Potter et al., 2003, *Earth Interactions*).



NEP-LO anomalies

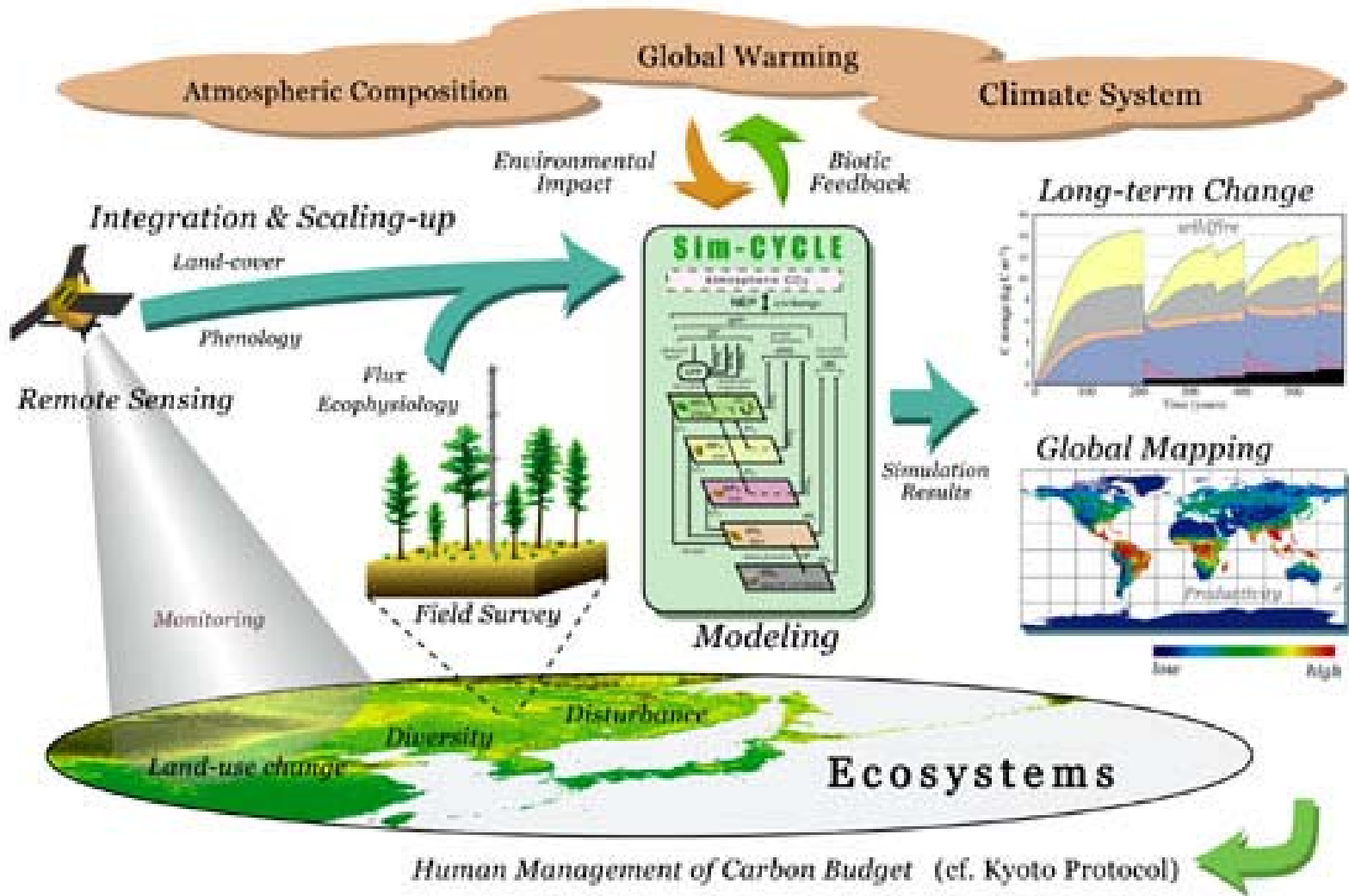


NEP-HI anomalies

(Color bar shows number of LO or HI anomalous events at each pixel location)

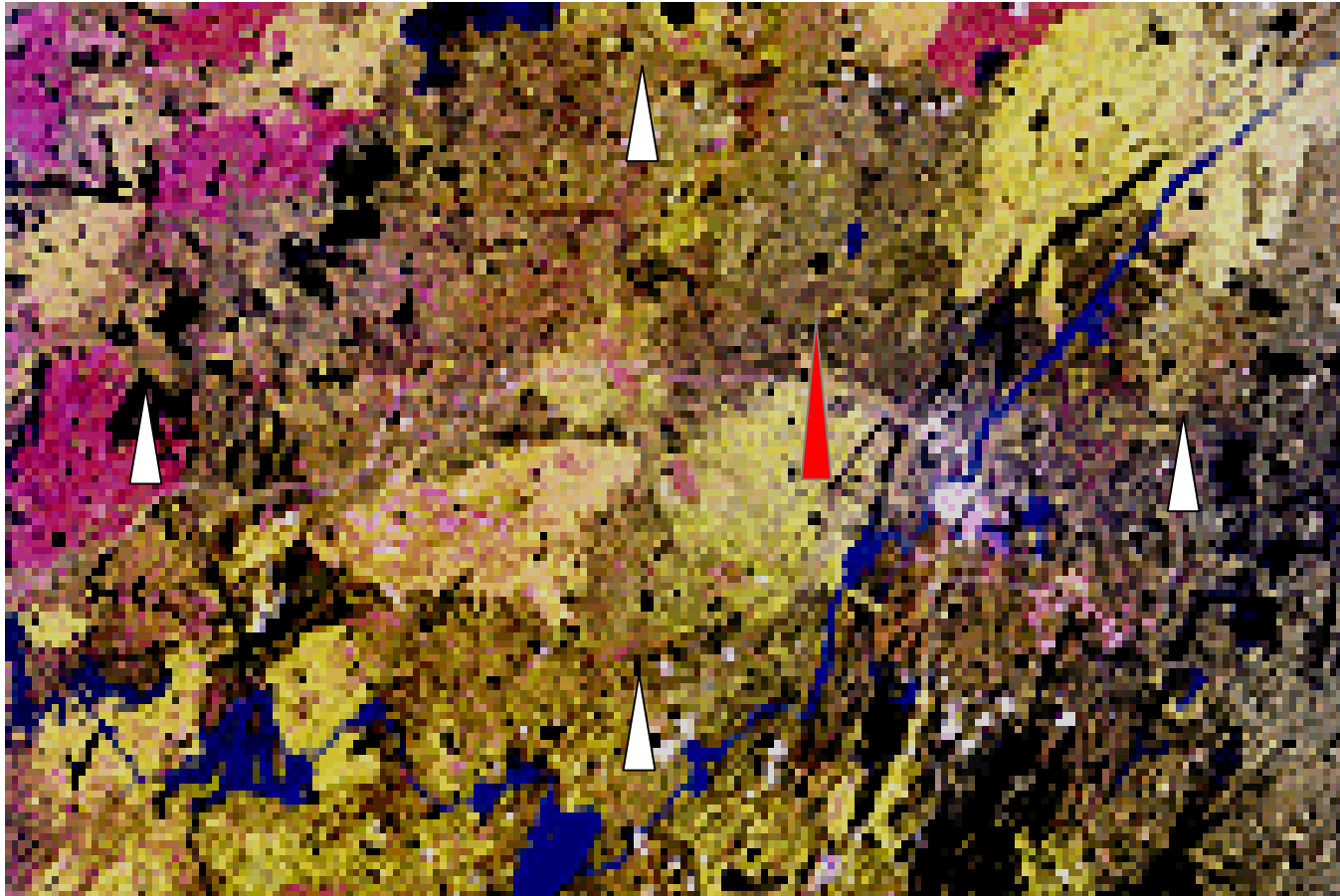
- **Areas of highest variability:** Northern Canada and Alaska, northern Rocky Mountains, central-western U.S. Great Plains and central farming region, southern U.S. and Mexico, and coastal forest areas of the U.S. and Canada.
- Variability in precipitation and surface solar irradiance are most closely associated with trends in carbon sink fluxes within regions of high NEP variability.

A Vision for Terrestrial Ecosystem Modeling and Remote Sensing



Frontier Research Center for Global Change (FRCGC)

Hypothetical Tower Cluster over Satellite Land Cover Map

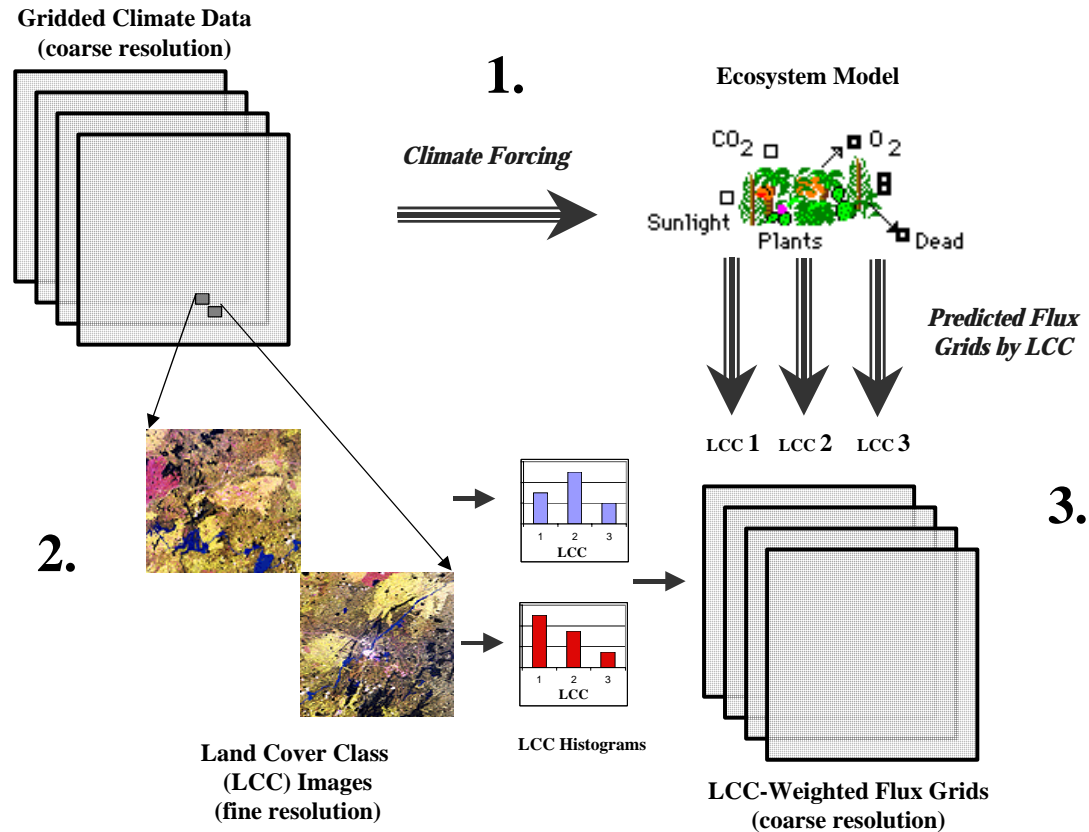


Main Tower Site



Additional (Tier 2-3 or Tower) Sites

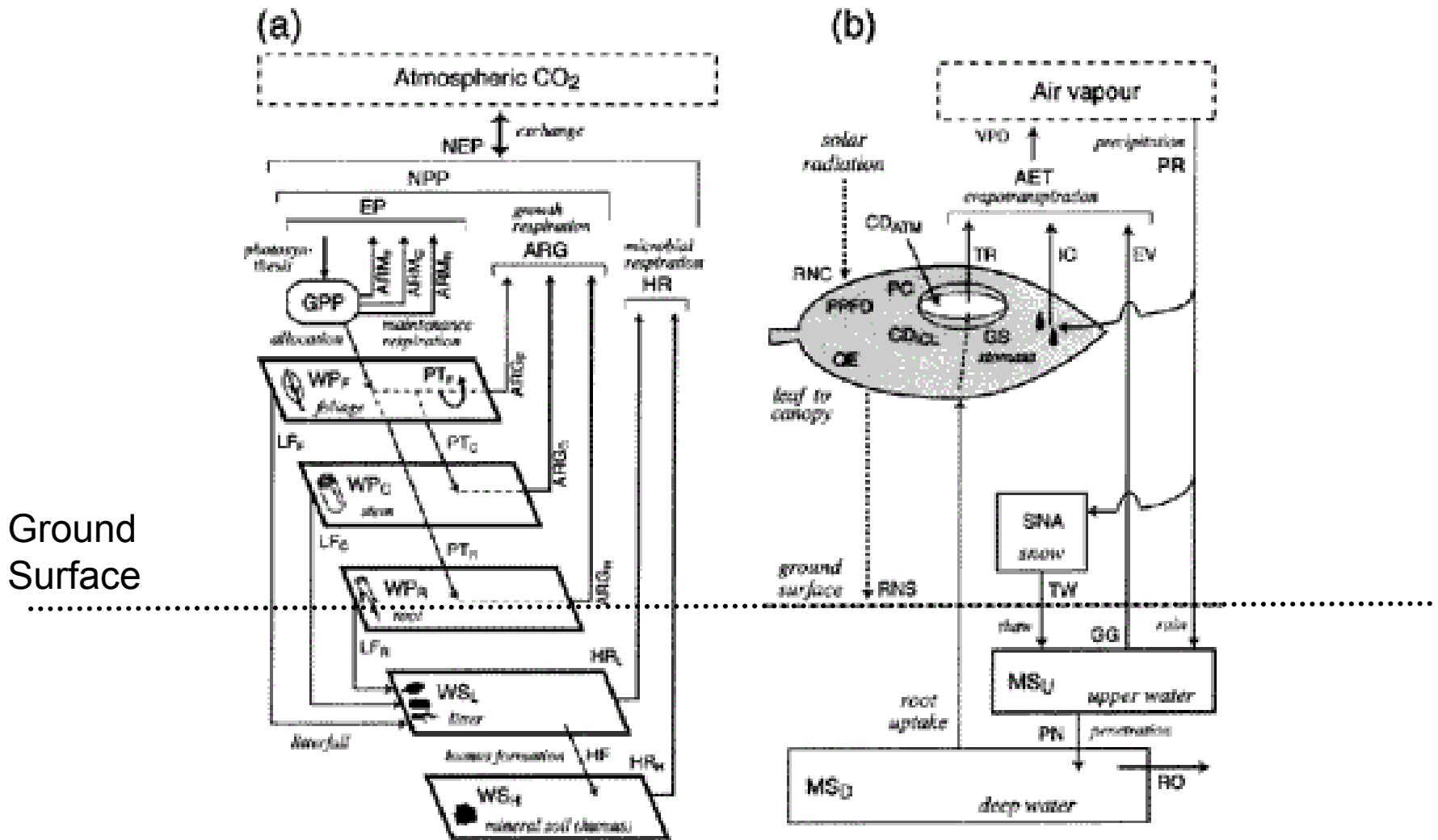
Flowchart for Ecosystem Model Carbon Predictions



1. Ecosystem model is forced by a time series of relatively coarse spatial resolution climate data for a series of predicted carbon fluxes based on individual land cover class (LCC) parameters.

2. Relatively high spatial resolution LCC histograms are derived from satellite image classification for tower cluster “footprint” areas.

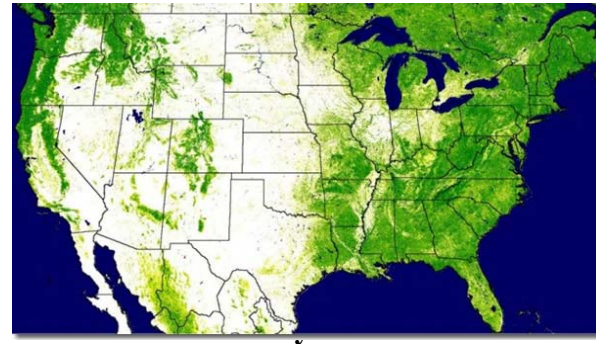
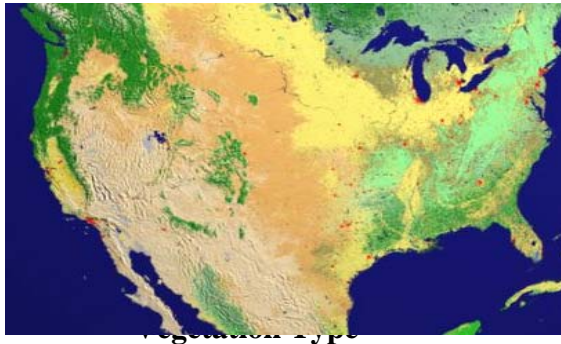
3. LCC-weighted flux grids are validated against tower fluxes by combining modeled flux predictions with the histogram frequency distributions for each LCC in the “footprint” image classification.



FRCGC Sim-CYCLE five-compartment system, foliage (WPF), stem (WPC), root (WPR), litter (WSL) and mineral soil (WSH); gross primary production (GPP), maintenance respiration (ARM), translocation (PT), growth respiration (ARG), litterfall (LF) and heterotrophic respiration (HR). Stomatal conductance (GS), intercellular CO₂ concentration (CDICL), light-use efficiency (QE) and photosynthetic carbon assimilation (PC) are determined interactively as functions of various environmental factors such as photosynthetic photon flux density (PPFD), atmospheric CO₂ concentration (CDATM), surface temperature (TG), soil-water availability (MS) and ambient vapour pressure deficit (VPD). Precipitation (PR) is partitioned into soil-water storage (MS), evaporation from soil surface (EV), evaporation from canopy (IC), transpiration from canopy (TR) and subsurface runoff (RO). Evaporation and transpiration depend on the input energy to the canopy (RNC) and soil (RNS) (Source: OIKAWA and ITO, 2001).

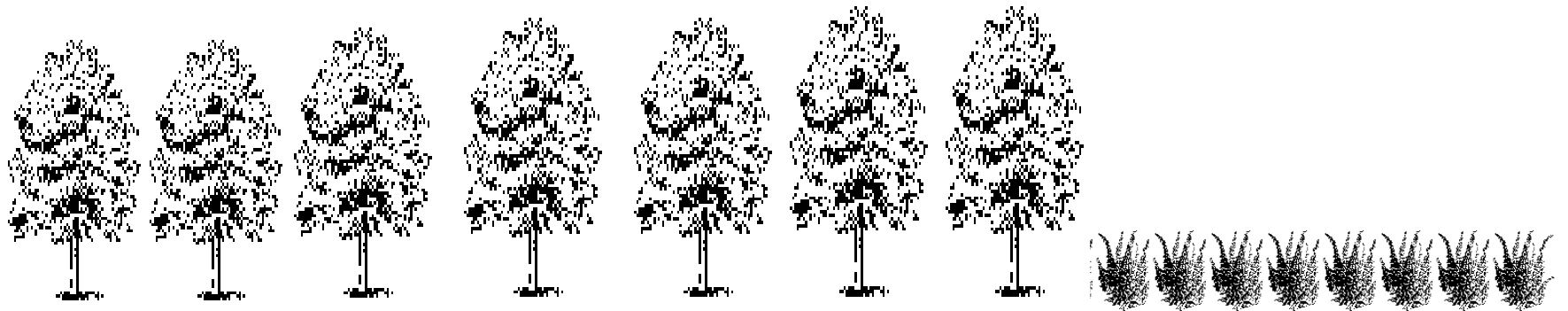
Potential Classification and Modeling Variables from Remote Sensing

- **Vegetation Type** (ETM+, MODIS 30-250 m)
- **Percent Woody Cover** (MODIS 500 m)
- **Leaf Area Index** (MODIS 250 m)
- **Stand Age** (ETM+, Lidar 30-100 m)
- **Topo-thermal Zone** (Shuttle Radar DEM 30 m)
- **Topo-hydro Zone** (Shuttle Radar DEM 30 m)



Key Question: Which variables (at what scales) capture the highest degree of spatial variability in carbon fluxes and pool sizes?

Chronosequence Cases for Dynamic Ecosystem Carbon Models



Science Priorities for NACP Modeling and Remote Sensing

Process-Level Information

Tree Height ---> Biomass Profile

Tree Age ---> Wood allocation : NPP

Soil Freeze-Thaw Effects

ALL THE ABOVE ---> Root Carbon

Live Wood C : Dead Wood C

Coarse Woody Decomposition

Site Selection and Scaling

Chronosequence Mapping

- Time since burning
- Time since tree harvest
- Time since ag. abandonment
- Time of woody encroachment

Consistent Continental Wetlands

- Classification System
- Satellite mapping

Gap “Issues” in the NACP Science Implementation Plan

“MODIS Land Cover defines 15 total classes. More detailed classifications are possible, but most BGC models cannot define more than a limited number of biome physiologies” (SIS, p. 18).

Ecosystem models are fundamentally reductionist and can readily specify many more plant physiologies than are currently offered in the MODIS Land Cover.

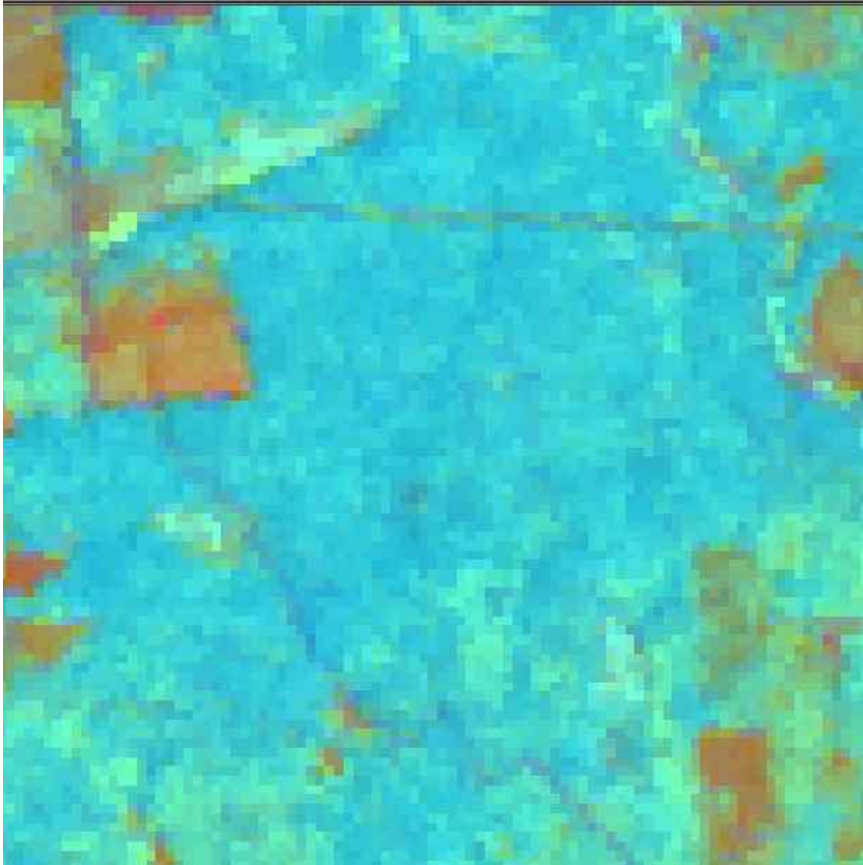
“NACP anticipates a network of 30 sites where vertical profiles of gases will be measured every other day using small aircraft” (SIS, p. 25 and Table 3).

The NACP focus of site studies over coastal margins and natural (unmanaged) ecosystems is not likely to offer enough data to address areas of most rapid (potential) change in land sources and sinks, i.e., managed (and/or fire-prone) woody ecosystems.

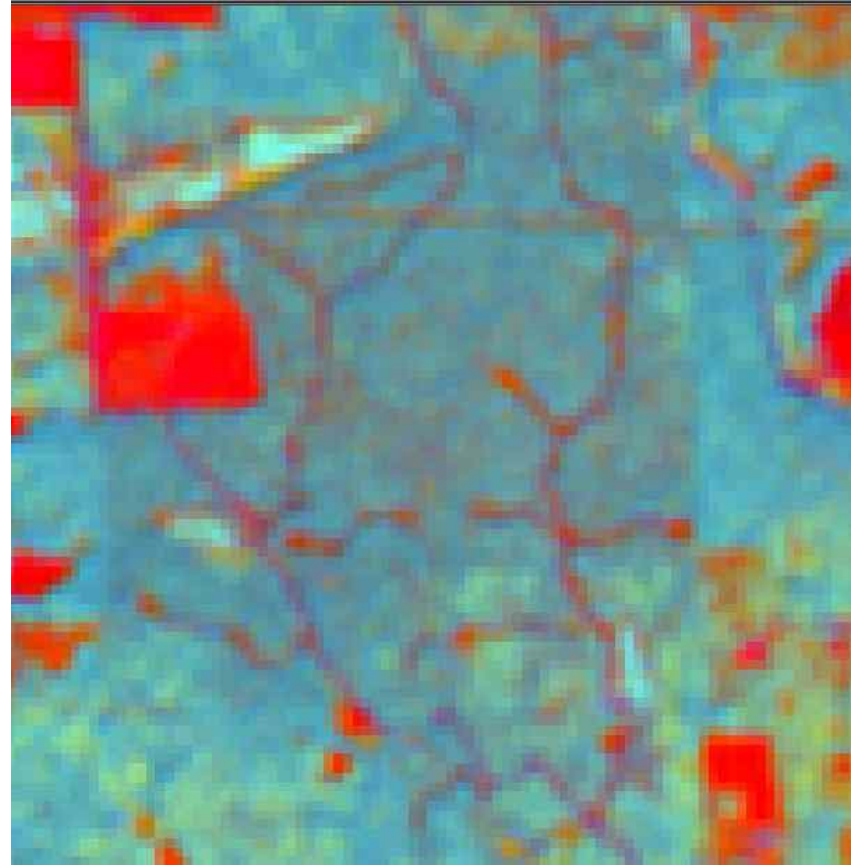
“How NACP can support decision making in enhancing and managing long-lived C sinks is still largely unexplored” (SIS, p. 25 and Table 3).

Interdisciplinary, spatially explicit modeling is called for, but there are no strong linkages yet to the land management activities and the carbon policy community for feedback.

Filling the Gaps for Carbon Management Impacts : Partial Forest Harvest



Pre-thin



Post-thin

TM scenes p45/r28, north of the Columbia River, WA. Red-brown areas in image at right are forests that have been thinned 1996-2000. (Source: Healey and Cohen, in prep).

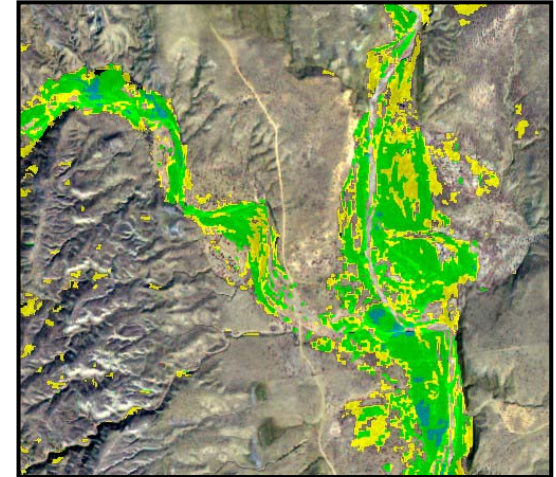
Filling the Gaps for Carbon Management Impacts: Invasive Species

Non-indigenous weeds are spreading and invading approximately 700,000 hectares of US wildlife habitat per year (Babbitt 1998).

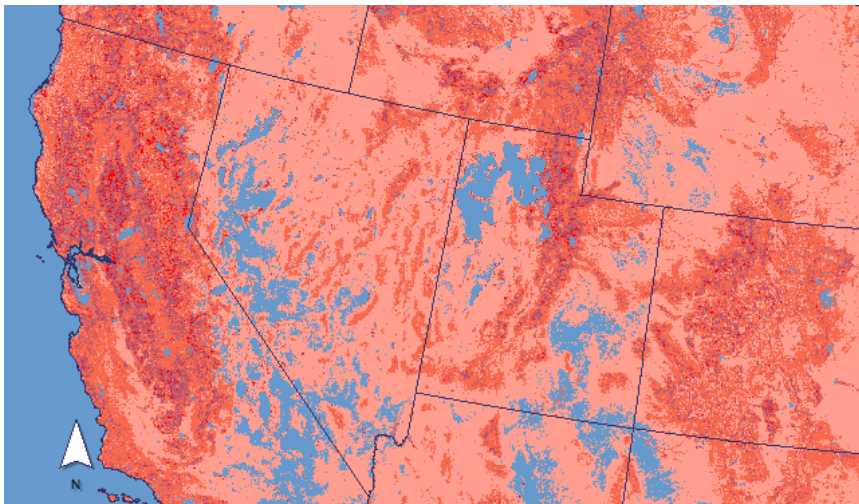
Salt Cedar (*Tamarisk*)



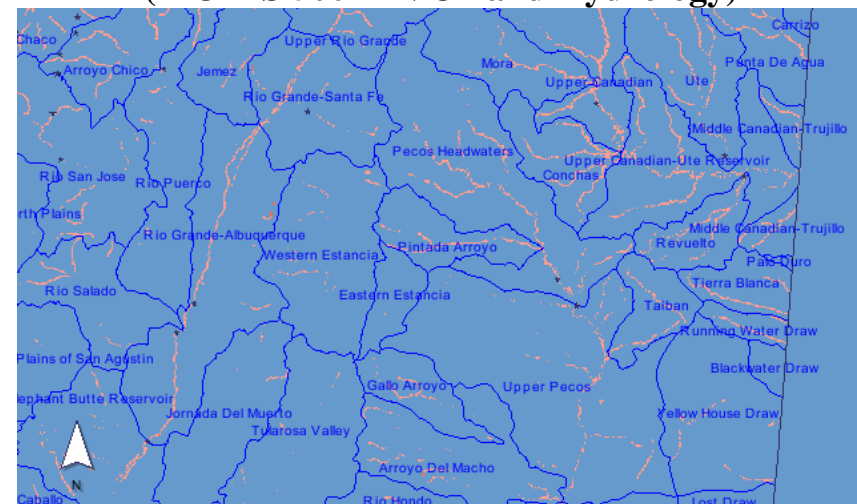
Mapping *Tamarisk* With High-Resolution Satellite Imagery (J. Stefanacci, USGS)



Invasive Grass Risk Map
(MODIS 500-m VCF and Growing Season VI)



Invasive Shrub Risk Map
(MODIS 500-m VCF and Hydrology)



CASA-CQUEST Application: A Decision Support Tool for Carbon Management

Supported by NASA Office of Earth Science Applications Division

Project Objectives:

- 1. Evaluate major forest and agricultural sinks of atmospheric CO₂ in the U. S. using EOS satellite data and ecosystem modeling.**
- 2. Support the U. S. Government interagency program for registration of voluntary GHG emissions reductions under the 1992 Energy Policy Act.**
- 3. Develop an internet-based Decision Support Tools (DST) of carbon sequestration in U. S. ecosystems for users nationwide.**

Investigators:

Christopher Potter and Matthew Fladeland (NASA ARC)

Steven Klooster, Vanessa Genovese, and Marc Kramer (CSUMB)



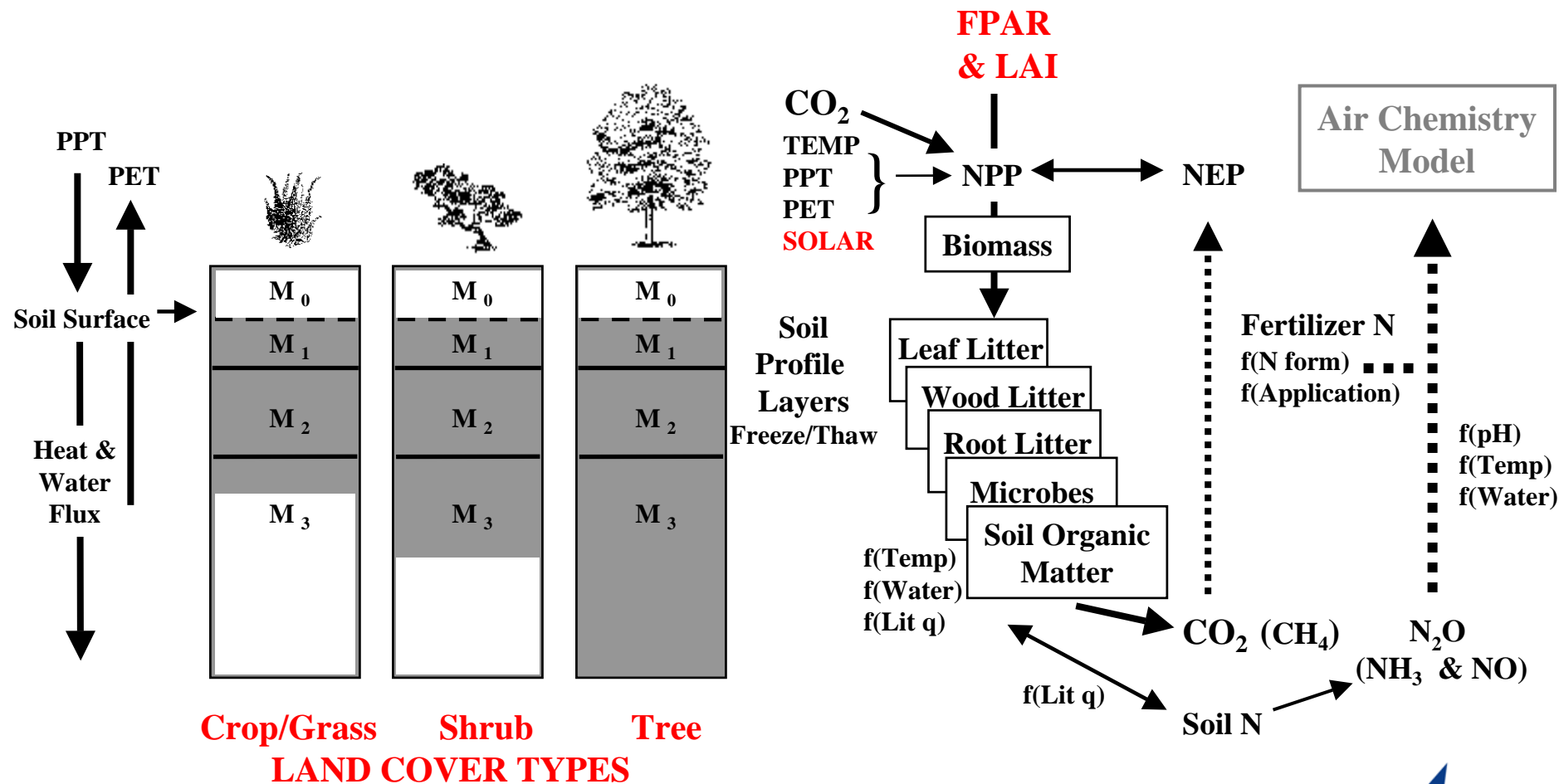
NASA-CASA Simulation Model

EOS Satellite Product Inputs

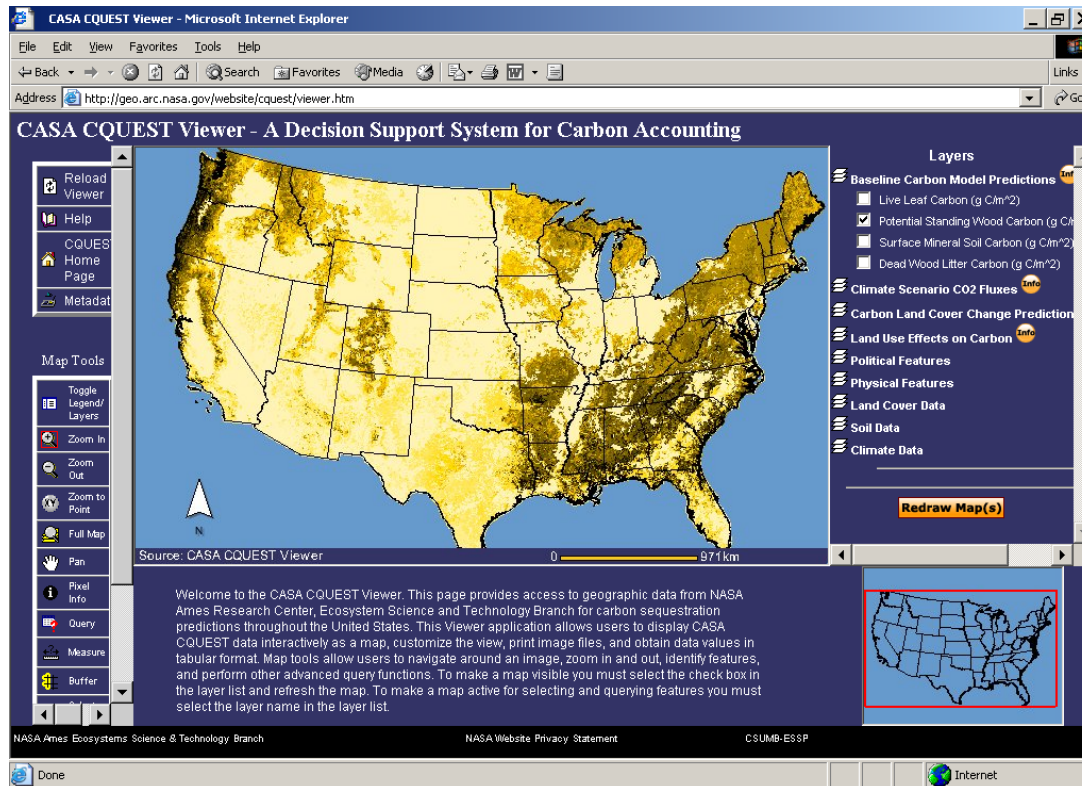
(a) Daily Soil Moisture Balance and Irrigation of Cultivated Land

(b) Plant Production and Nutrient Mineralization

(c) Fertilizer Application and Trace Gas Emissions



CASA-CQUEST Application: A Decision Support Tool for Carbon Management



The development of the CASA-CQUEST Decision Support Tools (DST) relies on “baseline” outputs and CO₂ flux predictions from the EOS-driven NASA-CASA model (Potter et al., 2003). CQUEST is an internet-based query and modeling application that allows users to display, manipulate, and save ecosystem model estimates of carbon sinks and CO₂ fluxes in agricultural and forest ecosystems for locations anywhere in the United States freely from a web browser. Users are able to customize the map views, navigate, overlay multiple data layers, print images, and obtain data values from any carbon map data layers in tabular format <http://geo.arc.nasa.gov/website/cquestwebsite>

Reference: Potter, C., S. Klooster, P. Tan, M. Steinbach, V. Kumar, V. Genovese, 2003. Variability in terrestrial carbon sinks over two decades: Part 1 – North America. *Earth Interactions*, Vol. 7, Paper 12.

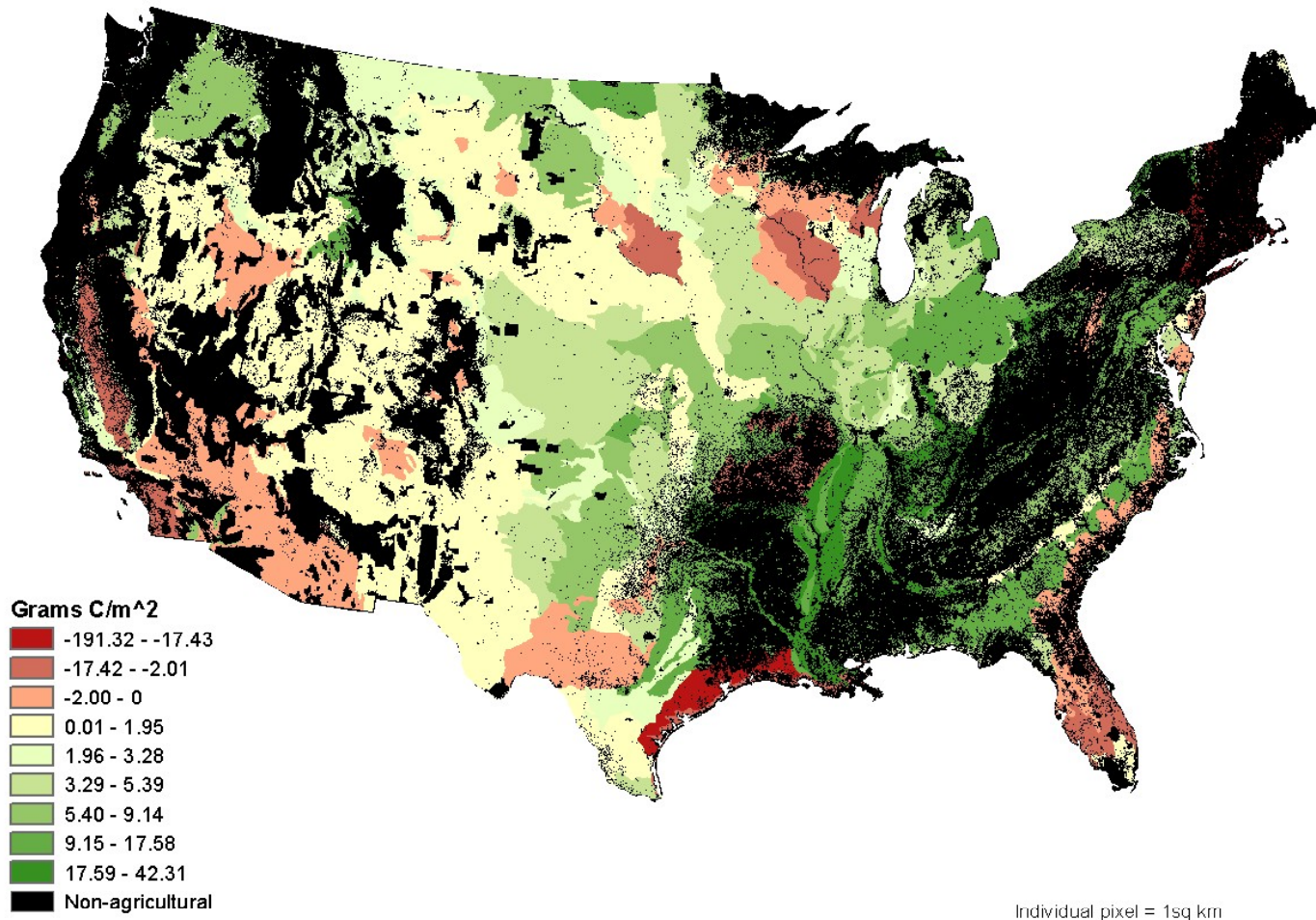
CASA-CQUEST Application: Expected Users and Contributions

The unique roles and contributions of this proposed DSS based on EOS remote sensing and the NASA-CASA carbon model, i.e., within the context of the overall USDA/NASA Global Change Program for CO₂ sequestration are:

- **National C sequestration inventory toward "entity-wide" accounting.**
- **Historical reconstruction of carbon pool baselines for the past 15-20 years.**
- **Simulation of future scenarios, e.g., land use change "avoidance" projections.**
- **Assessment of past and future climate variability and impacts of uncertainty.**
- **"Low intensity" afforestation and recovery of croplands to natural forest cover.**
- **Soil carbon changes in C storage.**
- **Dead wood changes in C storage.**
- **Changes in N₂O and CH₄ soil emissions with changes in CO₂ emissions and N inputs (fertilizer and deposition).**

“Agricultural data and analysis will be required to convert from county-level to spatial grids appropriate for model and merging with remote sensing” (NACP SIS, p. 17)

Estimated Annual Change in Carbon Pools in Agricultural Soils



Fusion of NRI reports, IPCC accounting methods, and MODIS 1-km Land Cover

Credits: Mark Sperow (West Virginia University), Keith Paustain (Colorado State University), Ronald Follett (USDA Agricultural Research Service), Seth Hiatt (San Jose State University), Vanessa Genovese and Peggy Gross (California State University Monterey Bay), Christopher Potter (NASA Ames)

Summary of Pending Remote Sensing Data Requirements for Terrestrial Carbon Cycle Modeling

- High resolution (250-meter or better) image products in areas of rapid change in woody biomass coverage
- Multi-temporal (seasonal or better) image products in areas of rapid land cover/use change
- Validation of high resolution surface radiation and precipitation data from remote sensing
- Reprojection (to conventional U.S. cartography) and accurate geo-rectification for all the above